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EQUIPMENT COMPARABILITY TECHNIQUES USED DURING EARLY SYSTEM DES--ETC(U)

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HUMAN RESOURCES

EQUIPMENT COMPARABILITY TECHNIQUES USED DURING EARLY SYSTEM DESIGN

By

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This report has been reviewed by the Information Office (OI) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

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A simple and accurate process is needed for comparing proposed equipment to existing operational equipment in order to forecast the resources required to support the proposed equipment. Maintenance manpower modeling needs such a process to predict manpower, spares, and support equipment of newly designed weapon systems.

As a first step toward developing the needed techniques for comparing old and new equipment, a systematic study was made of the present state-of-the-art. Current literature was reviewed, personnel who perform comparability analysis were interviewed, and past comparability studies were analyzed. This effort found that a distinction should be made between the broad topic of "comparability studies" and the specific procedures of

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"comparability analysis." A comparability study is the overall process used to estimate resource requirements for new equipment using the procedures of comparability analysis to find operational equipment which is similar to the proposed equipment.

It also was found that no standardized, reliable procedure exists for performing comparability studies including comparability analysis. It is recommended that a quantitative procedure be developed for comparing new equipment with equipment in the operational inventory. It is further recommended that a quantitative procedure be developed for computing an adjustment factor relating the operational equipment to the proposed equipment.

SUMMARY

Problem

An important step in the early estimation of manpower requirements for advanced weapon systems is an accurate "comparability study." A comparability study is the overall process used to estimate resource requirements for newly designed weapon systems by basing the estimate on the resources used by operational equipment that is similar to that of the proposed weapon system. The comparability study includes a "comparability analysis," which is the procedure followed to identify operational equipment similar to the proposed equipment. Simple yet accurate procedures are needed for performing both comparability studies and comparability analyses.

Purpose of the Study

The purpose of this investigation was to review the state-of-the-art regarding the procedures for performing a comparability study including comparability analysis. This effort had four principal objectives: (a) to review the printed guidelines available, (b) to determine the actual process in use, (c) to determine the comparability analysis methods in use, and (d) to determine the problems associated with comparability studies.

Approach

A review was made of the available literature and guidance to determine the recommended comparability study process. Then, material was reviewed on the Air Force comparability studies performed for the A-10, B-1, F-16, and YC-15 aircraft and the PLSS (Precision Location Strike System). Material on the failure rates of aircraft systems was also reviewed to determine the comparability techniques used. Finally, project engineers and administrators of comparability studies were interviewed to determine their involvement in the process and the problems they encountered.

Results

The four objectives of this study have been accomplished. First, the literature and guidance material were found to be very limited in scope. Second, the actual process used by engineers varied greatly from the limited guidance. Third, the methods used by the engineers were found to be undefined and not systematically structured. Finally, many of the problems arise from this lack of guidance and structure, resulting in confusion and doubts about the accuracy of the results.

Recommendations

It is recommended that a quantitative comparability analysis technique using such methods as scales, matrices, and regression analysis be developed. It also is recommended that a quantitative method, or technique, be developed for computing a data adjustment factor. A third recommendation is the development of a technique for determining the Mean Sorties Between Maintenance Actions for new equipment when comparable old equipment cannot be found.

PREFACE

This research effort was supported by the Air Force Human Resources Laboratory (AFHRL) under Work Unit ASDS 2036, Comparability Analysis of Newly Designed Weapon Systems. This effort was aided by the insight of Captain Larry Howell and Captain Albert Wong of the Engineering Specialties Division, Modeling and Analysis Branch (Aeronautical Systems Division of Air Force Systems Command), Wright-Patterson AFB, Ohio. The advice and guidance of Dr. William Askren, Mr. Robert Deem, and Mr. Frank Maher of AFHRL at Wright-Patterson AFB were the main directional force of this study. Appreciation is extended to the numerous engineers in the various system program offices working at Wright-Patterson AFB who worked on comparability analysis studies and to all of the individuals in the Modeling and Analysis Branch for their assistance and participation in the data collection phase.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

PAGES 2+4 BLANK

EQUIPMENT COMPARABILITY TECHNIQUES USED DURING EARLY SYSTEM DESIGN

I. INTRODUCTION

Problem

An important step in the early estimation of manpower and other resources requirements for advanced weapons systems is an accurate comparability study. A comparability study is the overall process used to develop data on newly designed weapons systems by (a) selecting operational equipment that is similar to that of the proposed weapon system and (b) adjusting the resource data associated with operational equipment to reflect the unique characteristics of the proposed equipment.

The comparability study includes developing maintenance demand rates for the proposed equipment which, in turn, can be used to determine resource requirements, such as spares, manpower, and support equipment for the weapon system. The comparability study also includes a comparability analysis, a systematic procedure for finding operational equipment that is similar to the proposed equipment.

A simple and accurate procedure is needed for performing comparability analysis. However, communications with systems engineering personnel[1] performing comparability studies, including the sub-effort comparability analysis, indicate that a simple and accurate procedure does not exist.

Purpose of the Study

The purpose of this investigation was to review the state-of-the-art regarding the procedures for performing a comparability study, including comparability analysis, and to define the areas of needed research for improving the procedures. This effort had four principal objectives: (a) to review the printed guidelines available for accomplishing comparability studies, (b) to determine the actual process used by the administrators[2] of comparability studies, (c) to determine the various comparability analysis methods used by the engineers[3], and (d) to determine the problems associated with performing comparability studies.

II. APPROACH

First, a review was made of the literature and guidance available to determine the recommended comparability study process. Second, material was reviewed on the Air Force comparability studies performed for the A-10, B-1, F-16, and YC-15 aircraft and the PLSS (Precision Location Strike System), and material was reviewed on the failure rates of aircraft systems by Shurman (Note 1) in order to determine comparability techniques used. Finally, 139 project engineers and four administrators of comparability studies were interviewed to determine their involvement in the process and the problems that they encountered. Of the engineers interviewed, 21 were with the A-10, 34 with the B-1, 36 with the F-16, and 48 associated with the YC-15.

III. RESULTS

Review of Printed Guidelines

The work of Tetmeyer (Note 2) is the only major guidance available on doing an equipment comparability study. A Boeing study, Shurman (Note 1), gave several unique methods for analyzing data which could be used to perform a comparability analysis of a specific subsystem. A combination of the

[1] Aeronautical Systems Division, Modeling and Analysis Branch (ASD/ENESA).
[2] An "administrator" for the purpose of this report is the individual who oversees the overall comparability study.
[3] The term "engineer" is restricted to the project engineer who performs the comparability analysis.

information in these two sources provides the general guidelines for accomplishing a comparability study and is described in the following paragraphs. However, no step-by-step process has been developed to aid engineers or administrators.

The approach recommended by Tetmeyer (Note 2) is to identify a comparable piece of equipment that is already in use for a similar purpose in a similar physical and operational environment and to use the field experience for it as a baseline for predicting maintenance frequency on the new equipment. This assumes that many of the unmeasurable factors will affect both items in a similar way and that any design deficiencies on the new equipment will be corrected during testing.

Every three-digit-level work unit code (WUC) on the new system should be paired with the same three-digit WUC on existing systems. This is because troubleshooting, functional checks, and adjustments cannot duplicate work, and many minor repair jobs usually are reported at this level. Within each subsystem, comparable items also would be identified for significant Line Replaceable Units (LRUs) at the four- or five-digit level. However, this level of information and configuration detail on the LRUs for the new equipment normally is not defined until the aircraft has completed design reviews during the full scale development phase.

Tetmeyer (Note 2) also designed a sample sheet which structured the data required from the engineers. The administrators only had to identify which subsystem a specific engineer was to analyze and provide him with the sample sheet. Required data included the comparable WUCs, the aircraft in which the subsystem was located, the adjustment factor, and the rationale in determining the adjustment factor.

There is seldom a perfect match between two pieces of equipment on all characteristics that could impact frequency of corrective maintenance. The mathematical methods described by Shurman (Note 1) can be used to help determine which equipment is comparable and the level of comparability. These methods give a statistical figure with which to adjust the data on the operational equipment identified. However, a few subsystems will be so different, or incorporate such new state-of-the-art components, that no comparable equipment can be identified. In these cases, the estimated maintenance frequency must be built up or factored from reliability demonstration data.

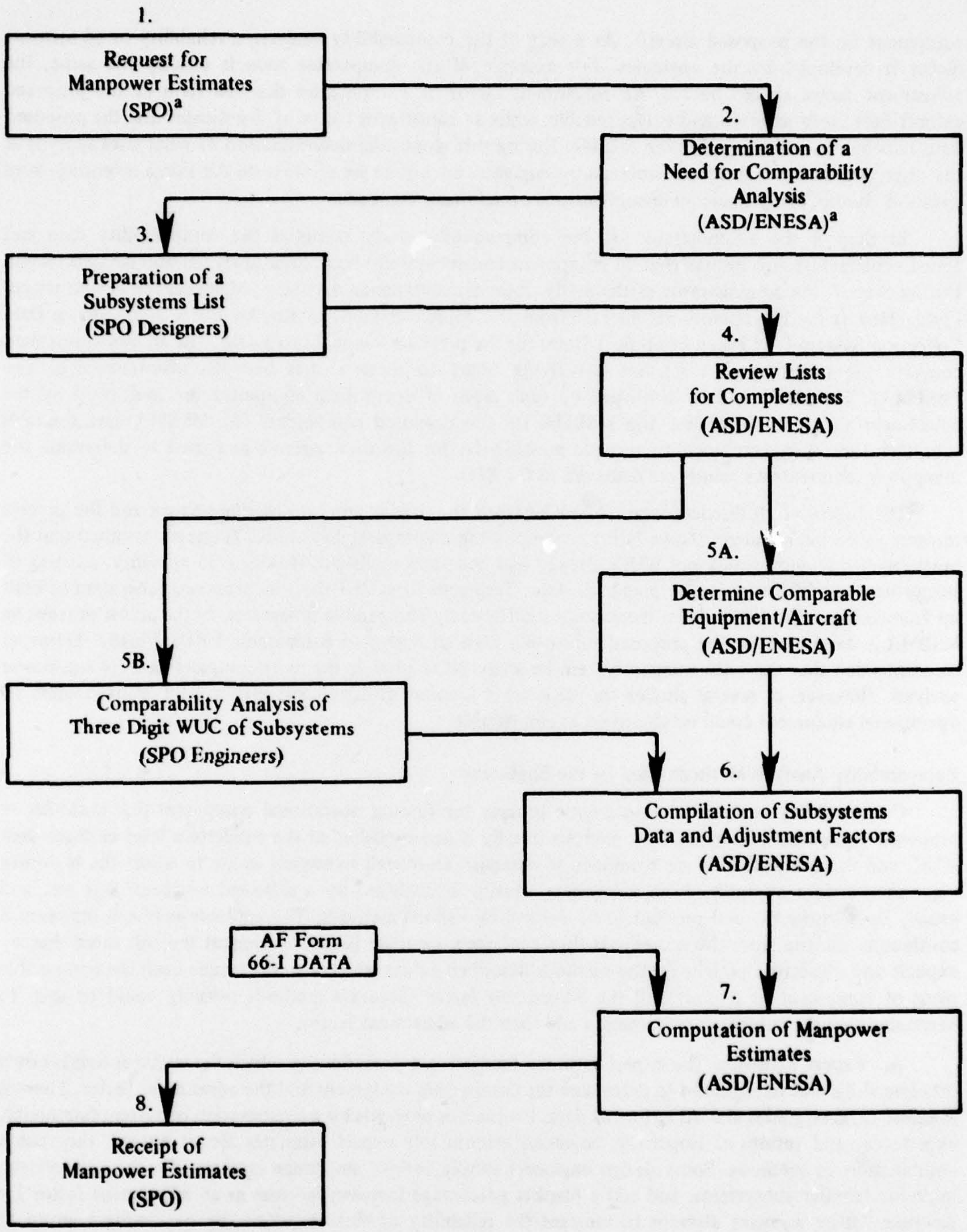
Actual Process Being Used in Comparability Studies

The following paragraphs and Figure 1 describe how a comparability study actually is being accomplished. First, the System Program Office (SPO) for the weapon system requests manpower estimates from the Logistics Composite Model (LCOM) Branch. Second, the LCOM Branch determines the need for a comparability analysis, and the administrator of the comparability study requests a list of proposed subsystems and WUCs for the total aircraft from the SPO. The third step is the preparation of the list of subsystems and WUCs for all equipment on the proposed aircraft by the SPO preliminary designers. Then the administrator of the comparability study in Step 4 reviews the lists for completeness and eliminates any overlapping WUCs. Steps 3 and 4 normally are accomplished simultaneously and interactively.

Next, the administrator divides the list into specific subsystems and decides who will determine the comparable equipment for each subsystem. Some administrators, Step 5A, choose to determine comparable equipment for some of the subsystems because of their knowledge of the equipment and the operational scenario. However, most of the subsystems are given to the SPO engineers to determine what is comparable, Step 5B.

During Step 5B, these requests and an instructional handout for accomplishing comparability analysis are delivered to the individual SPO engineers. Any problems or questions by the engineers during this phase are directly referred to the administrator of the study. The administrator is kept busy fulltime delivering and collecting questionnaires, answering inquiries, and explaining requirements. However, later in Step 5 of the development of a comparability study, the administrator can start managing the data already provided by some of the engineers.

After receiving the request to investigate the comparability of specific subsystems of LRUs during Step 5B, the SPO engineer determines what operational aircraft and equipment are comparable to the



[a]Responsible Organizations:
SPO – System Program Office
ASD/ENESA – Modeling and Analysis Branch

Figure 1. **Flow chart of comparability studies.**

equipment on the proposed aircraft. As a part of the comparability analysis, a reliability or adjustment factor is developed by the engineers. For example, if the comparable item is exactly the same, the adjustment factor should be 1.0. An adjustment factor of 2.0 indicates that the item of the proposed aircraft fails twice as often and is less reliable, while an adjustment factor of .5 indicates that the proposed item fails half as often and is more reliable. During this phase, the determination of what data apply is at the discretion of the engineer. However, most engineers are not aware of the total Air Force inventory from which to choose, hence inadequate comparisons occasionally are made.

In Step 6 the administrator of the comparability study compiles the comparability data and adjustment factors and insures that all equipment and subsystems have been analyzed and data corrected. During Step 7, the administrator of the study obtains maintenance data (e.g., Maintenance Manhours per Flying Hours) for the operational aircraft from the computer tapes of the Air Force Maintenance Data Collection System (Air Force Form 66-1 Data) for the previous 6 months to a year. The administrator then converts the maintenance manhours per flying hours to mean sorties between maintenance actions (MSBMA). The MSBMA data developed on each piece of operational equipment are multiplied by the adjustment factor to determine the MSBMA for the proposed equipment. The MSBMA data for each subsystem are then combined to provide an MSBMA for the total aircraft and used to determine the manpower requirements, which are delivered to the SPO.

The following differences were found between the actual process described above and the process recommended by Tetmeyer (Note 2) for accomplishing a comparability study. Tetmeyer assumed that the breakdown into subsystems and WUCs already had been accomplished. However, in actuality, a listing of subsystems and WUCs has to be prepared. Also, Tetmeyer suggested that the proposed subsystem be built up from comparable LRUs when there is not a sufficiently comparable subsystem. In the actual process, an MSBMA is developed for the proposed subsystem without regard to comparable LRUs. Finally, Tetmeyer recommended that the total weapon system be analyzed to provide the most complete data for manpower analysis. However, in several studies the data for a number of significant WUCs were omitted when no operational equipment could be identified as comparable.

Comparability Analysis Methods Used by the Engineers

Comparability analysis is a systematic process for finding operational equipment that is similar to proposed equipment. Comparability analysis usually is accomplished at the subsystem level or three-digit WUC, and the computations are combined to establish an overall numerical index to adjust the historical maintenance data available. Each subsystem usually is analyzed by a different engineer; this can, and usually does, cause the end product to be derived by various methods. The available methods represent a continuum, ranging from those methods that are largely intuitive (expert estimate) through those that are explicit and objective (modeling). The methods described below are used to determine both the comparable piece of equipment or aircraft and the adjustment factor. Separate methods possibly could be used to determine first the comparable equipment and then the adjustment factor.

A. *Expert Estimate.* The expert estimate method is a procedure in which the engineer uses his own intuitive skills and background to determine the comparable equipment and the adjustment factor. There is minimal reliance guides and other formal data. Estimation proceeds by a combination of system familiarity, experience, and intuition. Hopefully, engineers seldom rely expert estimates alone; instead, they use a combination of methods. Some design engineers simply review the design concepts for the new system, look for familiar subsystems, and add a blanket percentage increase/decrease as an adjustment factor for newness. Other agencies attempt to increase the reliability of their estimates by convening a group of experts and having them arrive at predictions through discussions. An important feature of the expert estimate method is that judgements can be made on unusual factors, such as environmental considerations.

B. *Historical Comparison.* The historical comparison method relates proposed equipment to similar operational equipment and uses the past experience of operational equipment to determine the resource requirements of the proposed equipment. Complete data are collected on the operational equipment and are kept on computer tape with programs available for data retrieval and system matching. Predictions for a

new system are made by considering the new system as a group of subsystems similar to those already in existence. The comparability data for the known subsystems are retrieved mechanically and serve as the basis for the predictions of the new subsystem. An adjustment to the prediction (increasing/decreasing) is made by expert estimates and/or abbreviated forms of the dominant factors and modeling methods. Data kept in the data banks are upgraded consistently as the actual information comes in for systems in the Air Force inventory.

C. *Dominant Factors (High Drivers).* The dominant factor technique of the estimation of comparability involves complex manipulation of hundreds of variables affecting equipment. A dominant factor, or high driver, (such as landing weight) is a single variable that stands ahead of a whole group of variables (such as steering, control, tires) and is critical to determining the comparability of two different landing gears. If an operational definition and early measurement of the dominant factor are possible, it will not be necessary to measure and interrelate the numerous variables represented by other factors.

Dominant concepts are sought to avoid the difficult task of accounting for multiple independent variables. The peril is that some revolutionary change in design or use of a weapon system will affect significantly the relationship of important variables on the dominant factor, thus destroying its utility as an index of comparability. Because of this risk, no engineer uses this method exclusively but backs up the estimates with other methods (usually some variant of the historical comparison).

D. *Modeling.* Modeling is a general category for all methods typified by their highly objective and explicit nature. Some of the procedures are graphic layouts, function-logic layouts, formula-review programs, and predictive math models (linear and dynamic programming, multiple regression expressions, etc). The methods specify in detail what data are necessary for use in the estimation technique, how the data are to be used in the model, and how to interpret the results. Judgements is not involved. The data goes into the model unaltered. Consequently, these methods have the advantage of being checked by different people running the same data through again and comparing the outcome. Modeling techniques could vary from simple rating scales to elaborate simulated systems which can be experimentally manipulated. Maintenance Manpower Modeling (MMM) and the LCOM are excellent examples of the usefulness and flexibility of modeling techniques.

Trend Toward Objectivity

The review of the comparability analyses performed by the engineers, as shown by Figure 2, revealed that the users of comparability analysis seem to be moving toward the objective end of the methods continuum. Older comparability studies (such as for the A-10 aircraft) relied more on intuitive methods (expert estimate 38%) and less on objective methods (dominant factors and modeling 10%). Newer studies (such as for the YC-14 aircraft) relied more on objective approaches (dominant factors and modeling 54%).

Methods	Totals	A-10	F-16	B-1	YC-14
Expert Estimate	43	8 (38%)	17 (47%)	5 (15%)	13 (27%)
Historical Comparison	40	11 (52%)	12 (38%)	8 (23%)	9 (19%)
Dominant Factors	43	2 (10%)	5 (14%)	15 (44%)	21 (44%)
Modeling	13	– (0%)	2 (6%)	6 (18%)	5 (10%)
	139	21	36	34	48

Figure 2. **Methods used by various SPO engineers.**

Problem Areas Associated with Comparability Analyses and Studies

A number of problems are associated with the comparability analysis. First, there is no standard comparability analysis method that is relatively accurate in the early stage of weapon system development. Second, a prediction often is made in a form that does not lend itself readily to making design changes. Third, the subjective element in the estimation occasionally is so large that the designers seem reluctant to accept the data and to make the important design changes. This is especially true when the method is of the "expert estimator" variety.

Furthermore, these problems associated with the comparability analysis have created additional problems with the overall comparability study. When a comparability study is being developed confusion arises as to when things should happen and in what sequence: for example: when is it best to initiate a comparability study, when should subsystems be listed, when should engineers develop the adjustment factors, and when should an update be done. Also, different subsystems have different significant parameters; hence, different comparability processes need to be developed specifically for each subsystem. Finally, the use of adjustment factors to account for failure rate variations between new and old equipment are sometimes objectionable, because the adjustment values generally are not known to an acceptable degree of confidence.

To help alleviate some of these problems, two separate techniques need to be developed. First, a standard, reliable technique is required for comparing equipment currently under design with equipment that is operational in the field to determine the operational equipment which is "most similar" to the newly designed equipment. Second, a standard, reliable technique is needed for computing the adjustment factor, which is used to modify the failure rate of old equipment to represent this failure rate of the new equipment.

IV. CONCLUSIONS AND RECOMMENDATIONS

The four objectives of this study have been accomplished and the findings are as follows. First, the literature and guidance regarding comparability analyses and studies are very limited. Second, the actual process used varies greatly from the guidance. Third, the methods used by the engineers were undefined and not systematically structured. Finally, many problems result from this lack of structure and guidance, causing confusion and doubts about the accuracy of the results. The following research studies are recommended in order to help structure the process and to provide more reliable and accurate comparability data:

1. Develop a systematic, quantitative, parametric comparability analysis technique using such methods as scales, matrices, and regression analysis.

2. Develop a systematic, quantitative method for computing the adjustment factor, and when subsystems are not sufficiently comparable, develop a technique for estimating the MSBMA for the new equipment.

3. Perform a time analysis of the comparability study flow of events in order to determine what needs to be done during a comparability study and at what times. Also, as a part of this study, the value of periodic updates of the comparability studies should be considered.

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